Ocean in situ sensor and technology requirements in preparation for the NASA PACE, GEO-CAPE and ACE missions

developed by the GEO-CAPE and ACE Oceans Science Working groups

PACE, GEO-CAPE and ACE pre- and post-launch algorithm development and validation goals require enabling investments in development of in situ observational capabilities. Emerging optical and biogeochemical sampling technologies should be advanced as appropriate for various platforms including moorings, piers and towers, autonomous underwater vehicles, unmanned aerial vehicles, autonomous profilers, large ships, small coastal boats, balloons, kites and offshore platforms. The objective is to expand the temporal and spatial coverage of key ocean properties (e.g., the apparent and inherent optical properties of seawater) and progress toward stable, autonomous and sustainable measurements. In this context, "stable" refers to a measurement with in situ recalibration or minimal drift from calibration, "autonomous" refers to an operational capability that is independent of human intervention, and "sustainable" refers to fault-free (or fault-recoverable) operation over periods of weeks to many months.

i) Radiometers:

Hyperspectral radiometers capable of high frequency sampling will be needed both for above water time series observations and high-resolution vertical profiling in shallow waters. Above water designs with automated solar-tracking capability and options for sky-radiance and sun irradiance measurements, in addition to water leaving radiance, will enable necessary advances in both in-water algorithms and atmospheric correction approaches. Required sensor specifications include spectral range of 340-900nm for in-water sensors and 340-1400nm for above-water sensors with high spectral resolution, ideally 2nm spectral sampling between 380-800nm spectral range, 5nm spectral sampling between 340-380nm and 800-900nm and 10nm spectral sampling between 900-1400nm, and capability to measure the bidirectional reflectance distribution function (BRDF). In order to capture the variability in the light field, in situ radiometers must have sufficiently slow descent rates (≤ 20 cm s^{-1}) and sampling frequencies on the order of 10 hertz or greater to permit <1 cm sampling resolution within optically complex coastal waters. In situ sensors should also address the control of biofouling for long-term deployment between servicing and reduction in size and power requirements to enable longer deployments and smaller autonomous platforms. Reduction in instrument size is also desirable to minimize self-shading, especially in turbid waters. Sensor accuracy and precision must be sufficiently high to achieve an overall uncertainty of 1% when taking into account all measurement uncertainties in the field.

ii) IOP sensors:

Advances in capabilities of in situ instrumentation for measurements of inherent optical properties (IOP) permit the collection of ground truth information in support of algorithm develop and validation of products relevant to the PACE, GEO-CAPE and ACE ocean ecosystem missions. Measurements of fundamental optical properties should include multispectral and hyperspectral absorption, scattering, backscattering, and volume scattering function. Required advances from current technologies include: (a) built-in calibration, (b) capabilities to discern vertical structure in coastal waters including resolution of the top 5-10cm of the water column, (c) easier to use sensors, (d) hyperspectral backscattering sensors, (e) control of biofouling for long-term deployment between servicing, and (f) reduction in size and power requirements to enable longer deployments and smaller autonomous platforms. The information from these new technologies will be critical in understanding the basis for observed variations in remote sensing reflectance signatures and their relationship to optical properties and associated constituents that influence them. Currently available instruments are optimized for coastal, high-biomass regions with high signal. Improvements are required in instrument stability, resolution, and effective range. Development of sensors that will measure IOPs in the UV-A wavelength bands (320-400 nm) and near infrared for spectral coverage of 340-900 nm is also required. Sensors must be capable of achieving the accuracy and precision metrics summarized in the following table.

Variable	**Precision**	**Accuracy**
Absorption coefficients	0.001 m^{-1}	Max. 0.005 m^{-1} or 5% of signal
Attenuation coefficients	0.001 m^{-1}	Max. 0.005 m^{-1} or 5% of signal
Scattering coefficients	0.001 m^{-1}	Max. 0.005 m^{-1} or 5% of signal
Backscattering coefficients	0.00001 m^{-1}	Max. 0.00005 m^{-1} or 5% of signal
Volume scattering function	0.000001 m^{-1} sr^{-1}	Max. 0.000005 m^{-1} sr^{-1}or 5% of signal

iii) Biogeochemical sensors:

Algorithm development and validation requires advances in sensors that provide direct or proxy information about products or constituents of interest, especially emerging technologies that characterize suspended particles (size distribution, shape and composition), plankton (phytoplankton functional type/group), nutrients and other chemicals (biomarkers, hydrocarbons, etc.), organic and inorganic carbon system components (including pH), and rate processes (respiration, carbon fixation, nutrient uptake). Approaches to be explored include optical spectrometry, mass spectrometry, flow cytometry, optical imaging, multi-isotope incubation, and other analytical techniques that can be automated in a robust manner.

Proposals are sought to develop new methods of characterizing marine particles and particle assemblages in situ. "Particles" refer to both living and non-living components of seawater. Approaches should focus on new methods of characterization that are non-destructive, especially with respect to fragile particle aggregations, and non-invasive, preserving to the extent possible the relational and orientation aspects of individual particles within a population. Applications should be directed toward the optically-relevant particle size range from 0.1 - 50 µm, which are of greatest interest, but should also be capable of relating observations to the larger, acoustically-relevant size ranges.